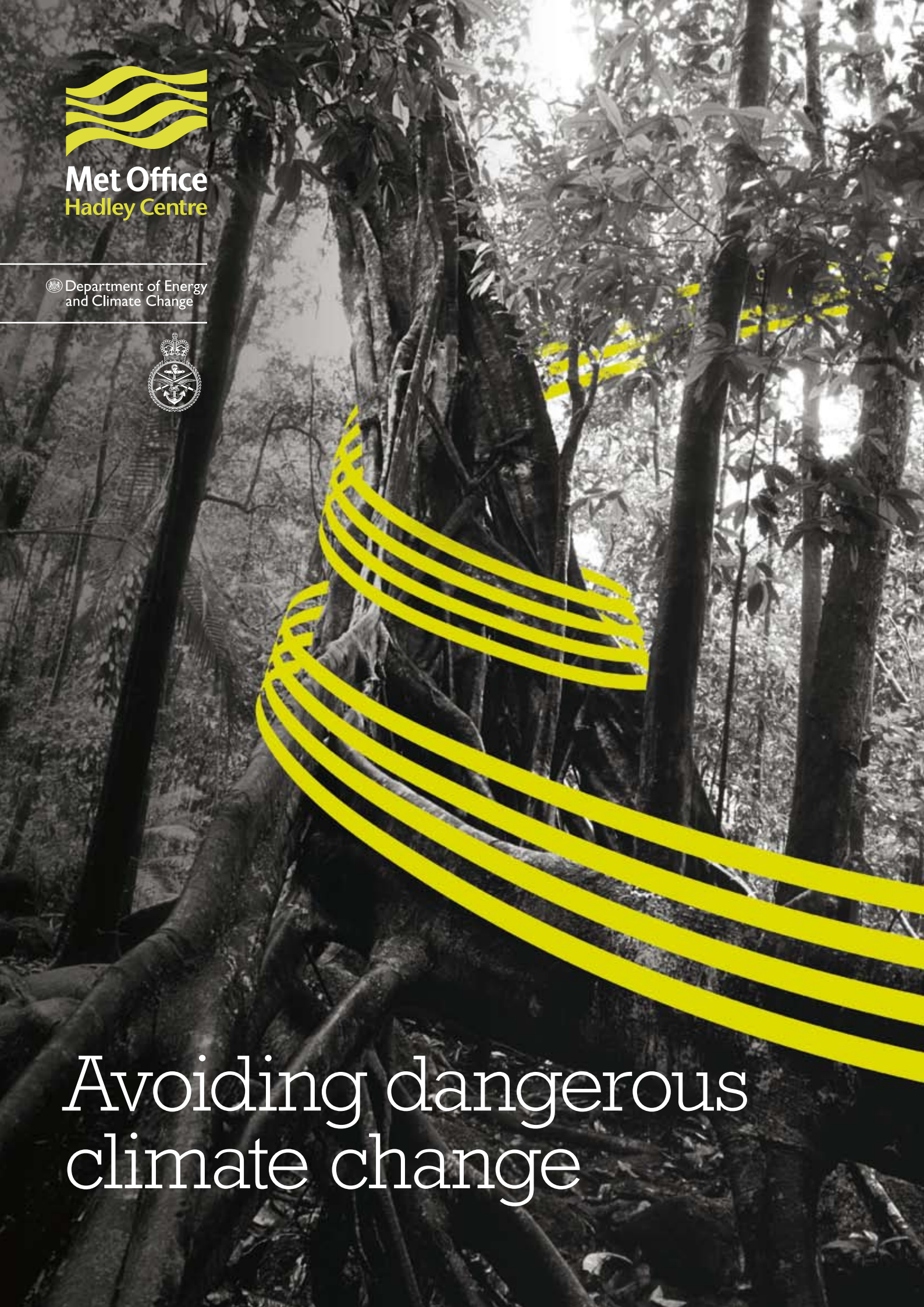


Avoiding dangerous climate change

Introduction

The latest results from the Met Office Hadley Centre add to the increasing evidence that early and rapid reductions in emissions are required to avoid significant impacts of climate change.

Here, we present the latest evidence of continued change and projections based on current models and understanding. Finally, we highlight several emerging science issues that could make climate change more dangerous than previously expected.

- The indications are that climate is continuing to warm due to increasing man-made greenhouse gases. We provide an update on changes in global temperature, UK temperature and Arctic sea ice.

- The latest climate model projections show that the risks of dangerous climate change increase rapidly as greenhouse gas concentrations increase.

- Many of the dangers of climate change are made worse by interactions between the climate, chemistry, biological systems and fresh water. These are important because they have impacts on water availability, air quality and human health. We highlight:

  - Examples of these interactions and improvements in climate modelling to represent them.
  - The impact of climate change on air quality and health.
  - The impact of land use change, in particular deforestation, on emissions targets.

Evidence of continuing climate change

Global warming

The evidence is clear – in the long term, global temperatures are rising

Some commentators have suggested that global warming has stopped. This is not the case. The evidence is clear – in the long term, global temperatures are rising, and humans are largely responsible for this rise.

Global warming does not mean that each year will be warmer than the last – natural phenomena mean that some years will be much warmer and others cooler. The El Niño in 1998 gave rise to a record-breaking warm year and the La Niña in 2007 and 2008 led to temporary cooling. Despite this, 11 of the last 13 years are the warmest ever recorded.

Average global temperatures are now some 0.75 °C warmer than they were 100 years ago. Since the mid-1970s, the increase in temperature has averaged more than 0.15 °C per decade. This rate of change is very unusual in the context of past changes and much more rapid than the warming at the end of the last ice age. Sea-surface temperatures have warmed slightly less rapidly than the global average, whereas temperatures over land have warmed more rapidly, at almost 0.3 °C per decade.

Over the last ten years, the rate of warming has been slightly lower than during previous decades. But this does not mean that global warming has slowed down or even stopped. It is entirely consistent with our understanding of natural fluctuations of the climate within a trend of continued long-term warming.

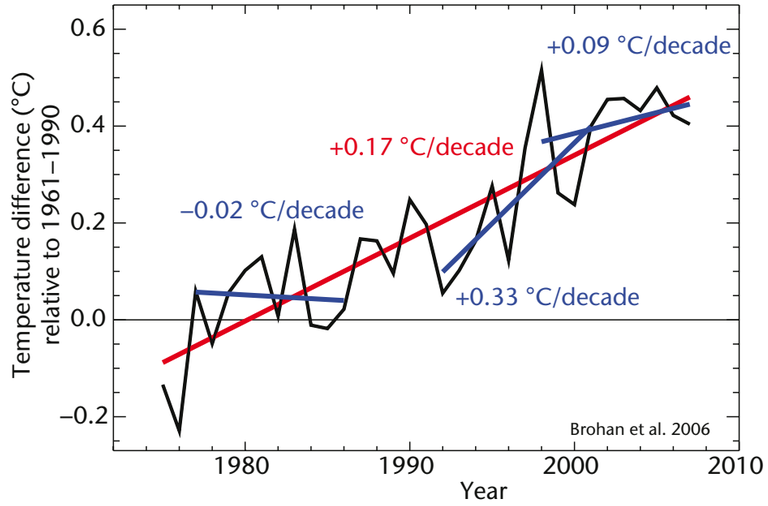


Figure: Global average temperature anomaly from 1975–2007, relative to the 1961–1990 average. The black line shows the annual values. The red line shows the trend over the full 33 years. The blue lines show the varying rate of the trend over various 10-year periods.

These natural fluctuations include the El Niño Southern Oscillations (ENSO) in the Pacific Ocean. In El Niño years – those when there is no cold surface water in the tropical eastern Pacific – global temperature is considerably warmer than normal. A particularly strong El Niño occurred in 1998, resulting in the warmest year on record across the globe.

In La Niña years – when more cold water rises to the surface of the Pacific Ocean – temperatures can be considerably colder than normal.

Volcanic eruptions can also cause temporary drops in global temperatures because of huge amounts of aerosols thrown high into the atmosphere that reduce the amount of sunlight that reaches the surface.

A La Niña was present throughout 2007 and much of 2008, but despite this temporary cooling, 2008 is currently the tenth warmest year of the global record

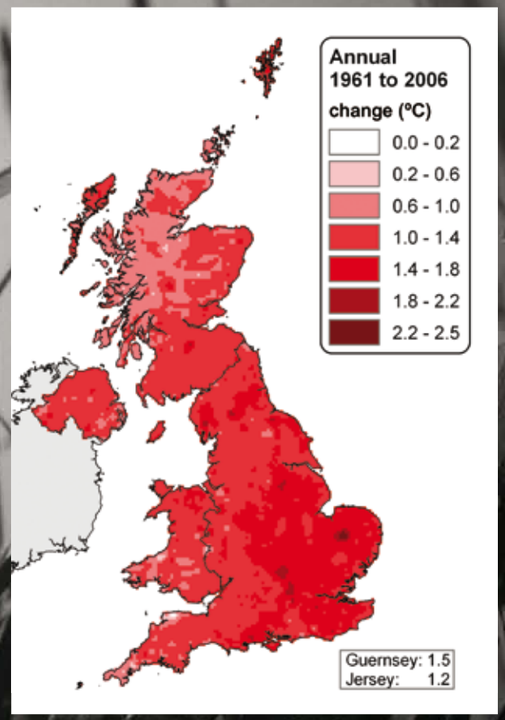
As a result of such fluctuations, global average temperature trends calculated over 10-year periods have varied since the mid-1970s, from a modest cooling of -0.02 °C per decade, to a warming rate of more than 0.3 °C per decade. Model projections of future climate change forecast that temperatures will rise by more than 2 °C per century. However, even with this long-term rise, natural variations in climate can be expected to lead to ten-year periods with little or no warming, both globally and regionally, and other ten-year periods with very rapid warming.

This complex behaviour of the climate system shows why we need to examine much longer periods than 10 years if we are to fully understand and quantify how the climate is changing. In its most recent assessment in 2007, the IPCC[1] concluded that increases in man-made greenhouse gas concentrations are “very likely” to have caused most of the increase in global average temperatures since the mid 20th century.

[1] Intergovernmental Panel on Climate Change

UK temperatures

The UK has experienced marked trends in climate in the last 45 years. Much of the UK has warmed by more than one degree Celsius since 1980, with 2006 being the warmest year in the 350-year long Central England Temperature record.



The global long-term warming trend is set to continue as the concentration of greenhouse gases in the atmosphere continues to increase. Inevitably, this will lead to further impacts on our lives and the world's natural ecosystems. Heatwaves and droughts are likely to become more prevalent; snow cover is projected to continue to diminish; and sea ice to continue to shrink. On shorter timescales, natural climate variations and other factors, such as volcanoes, will continue to temporarily enhance or reduce the magnitude and impacts of these longer-term changes.

Figure: Changes in annual average daily minimum temperature (°C) between 1961 and 2006 based on a linear trend (as developed on a high resolution 5 km grid by the Met Office's National Climate Information Centre).

Arctic sea ice

Human activity is already contributing to reductions in Arctic sea ice. We are heading for ice-free Arctic summers, despite an expected short-term recovery from the dramatic sea-ice loss of 2007.

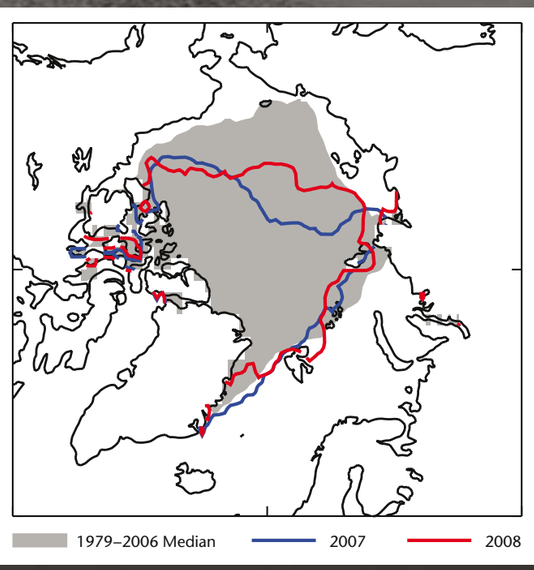


Figure: Sea ice extent for September 2007 and 2008.

The extent of Arctic sea-ice cover in September 2008 was the second lowest since records began; only surpassed by the record minimum in 2007. The recent dramatic ice loss adds to the long-term trend observed over the last 30 years. The latest Met Office Hadley Centre results strengthen the evidence that human activity is already contributing to decreases in sea-ice extent, and will lead to ice-free summers later this century. The dramatic losses in 2007 and 2008, however, may well be temporary. Nevertheless, people and ecosystems are already responding to the changes.

In September 2007, sea-ice extent was only around 60% of the average value for 1979–2000, and the Northwest Passage, joining the Atlantic and Pacific via the northern coast of Canada, was ice-free for the first time in living memory. The extent of ice coverage did not fall as low in 2008, but it was only just behind (within 10% of) 2007, reinforcing the long-term decline in sea ice, at least since satellite records began in 1979.

The large sea-ice retreat in 2007 occurred particularly in areas to the north of Siberia and Alaska. The retreat was largely a result of unusual high pressure, leading to sunny skies which increased warming and melting, and southerly winds which pushed the ice edge north. In contrast, the ice-cover retreat in 2008 was mainly from the Siberian coast and the Greenland Sea. It may also have been affected by weather conditions, but another factor may have been the record low ice extent in 2007, which meant that winter ice cover in 2008 was thinner than usual.

New results from the Met Office Hadley Centre show that there is a detectable human influence on the long-term decrease in sea-ice extent for some months of the year. In particular, for the satellite record over the last 30 years, human influence is detectable in every month between June and October, and also in the annual total. This detection has only just become possible in the satellite record, which was too short before. The next stage of the work will be to look at whether changes in ice thickness can be similarly accounted for.

Met Office Hadley Centre model simulations have been used to look at whether the record low ice extents in 2007 and 2008 are a signal that a tipping point has been reached in the Arctic climate system.

Results from our model show that large year-to-year variations are possible with some dramatic temporary losses over one and two-year periods which are consistent with the observed losses of recent years. Thus, these rapid losses are expected to be largely reversible over a few years. The model results are credible because they are consistent with the observed long-term trend in contrast to results from many other models which underestimate the trend. There is no strong evidence that a threshold or tipping point has been reached, although it is still an open question and further research is required.

When our model is run into the future using one of the IPCC emissions scenarios, it projects summers largely free of Arctic sea ice by the 2060s.

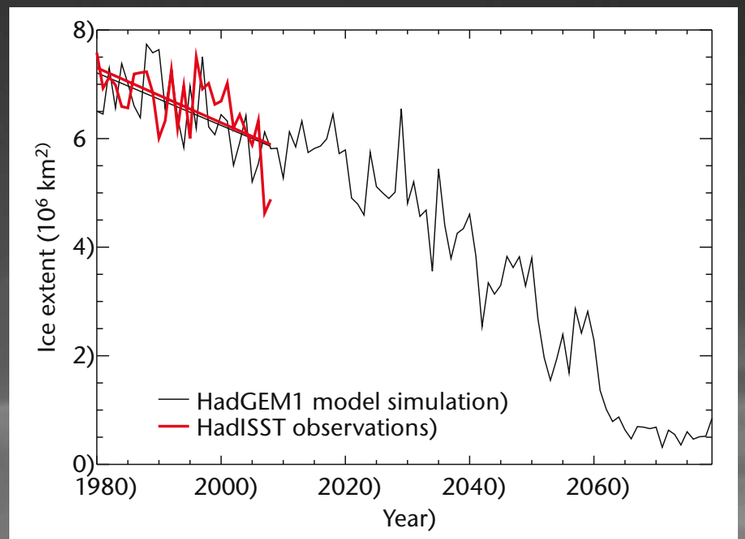


Figure: September Arctic sea-ice extent. The black curve is the Met Office Hadley Centre model simulation and the red curve is observations.

However, it is important to note that there is still considerable uncertainty in sea-ice projections. For example, a different, credible climate model has projected an earlier ice-free date.

The Met Office, in collaboration with the EUMETSAT Ocean and Sea Ice Satellite Application Facility, has developed a new sea-ice dataset based on satellite data which will help to determine if sea-ice recession is accelerating. Further model development and evaluation is needed to ensure that the detailed ice structure and evolution is being captured correctly. This work is being done with partners in the UK and internationally, and will help us to tell whether a tipping point has been reached.

The scientific evidence for early action on climate change[2]

Even with large and early cuts in emissions, temperatures are likely to rise to around 2 °C above pre-industrial levels by the end of the century.

Only an early and rapid decline in emissions gets anywhere close to the target of a 50% reduction in emissions by 2050.

If we are concerned about keeping the risks of dangerous climate change to a minimum, we should also consider the worst-case outcome.

The latest climate model projections from the Met Office Hadley Centre show clearly that failure to cut emissions sufficiently could have significant consequences for the world's climate. Even with large and early cuts in emissions, projections indicate that temperatures are likely to rise to around 2 °C above pre-industrial levels by the end of the century. If action is delayed or slow then there is a significant risk of much larger increases in temperature, with some severe impacts. Uncertainties in the science mean that even if the most likely temperature rise is kept within reasonable limits, we cannot rule out the possibility of much larger increases. Additional adaptation strategies are therefore needed to deal with these less likely, but still real possibilities.

When it comes to climate change, scientific evidence provides critical information for decision making.

Governments need to understand the consequences of choosing particular targets, but they also need to understand what will happen if targets are missed or if they cannot be agreed by all countries. Failures could have far-reaching consequences.

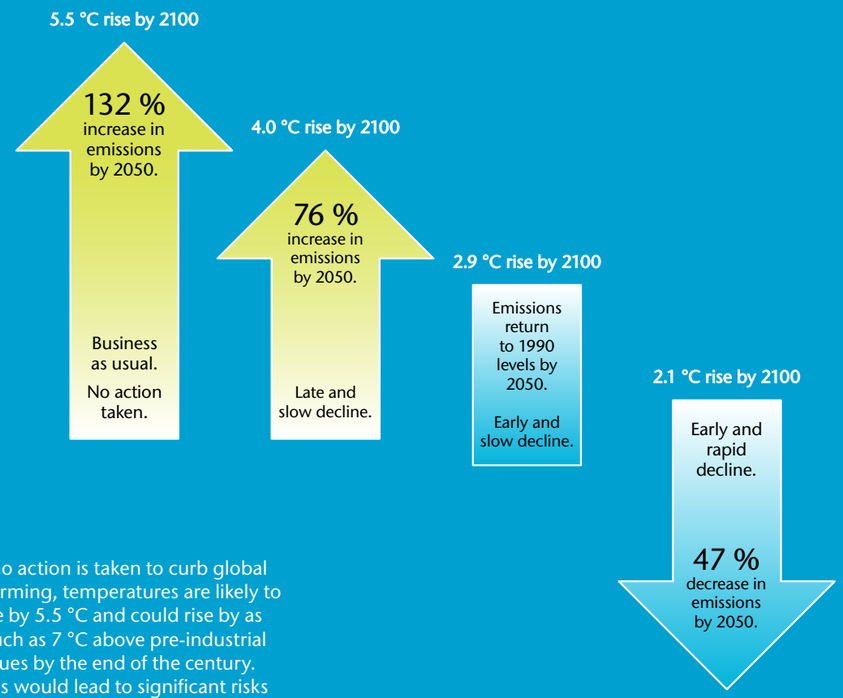
Met Office Hadley Centre scientists have conducted a series of 'what if?' climate projections, to give a better understanding of the temperature rises we could expect if action on reducing greenhouse gas emissions is slow or delayed.

In the first scenario, emissions continue to rise throughout the century. In the other scenarios, emission reductions have been imposed at various times and at various rates.

[2] Reproduced from article by Vicky Pope in the Guardian, Oct 1st 2008
[3] IPCC Special Report on Emissions Scenario A2, medium to high emissions

Emissions increases from 1990 levels

Most likely global temperature rise relative to pre-industrial levels:



If no action is taken to curb global warming, temperatures are likely to rise by 5.5 °C and could rise by as much as 7 °C above pre-industrial values by the end of the century. This would lead to significant risks of severe and irreversible impacts.

In the most optimistic scenario, emissions start to decrease in 2010 and reductions quickly reach 3% per year. This contrasts sharply with current trends, where the world's overall emissions are increasing at 1% per year. This is faster than even the worst cases used in the IPCC emissions scenarios.

Figure: Temperature rises for a 'business as usual' scenario and three emissions reductions scenarios. The numbers indicate the most likely (i.e. 50% chance) temperature rises compared with pre-industrial temperatures. Temperatures are already 0.75 °C above pre-industrial values. The projections used a simple climate model calibrated against complex climate models. The 'business as usual' baseline scenario is based on the IPCC SRES A2 scenario[3], but with aerosols decreasing from 2010. This is done to be consistent with the other scenarios. Aerosols are likely to decrease in the drive to improve air quality, even if greenhouse gas emissions continue to rise. This adjustment means that the 'business as usual' results are around 1 °C warmer by 2100 than the standard IPCC A2 scenario results.

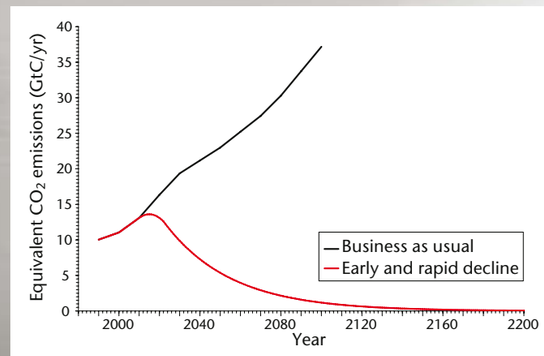


Figure: Shows the emissions for the three major greenhouse gases (CO_2, CH_4 and N_2O) combined into a carbon equivalent for two emissions scenarios.

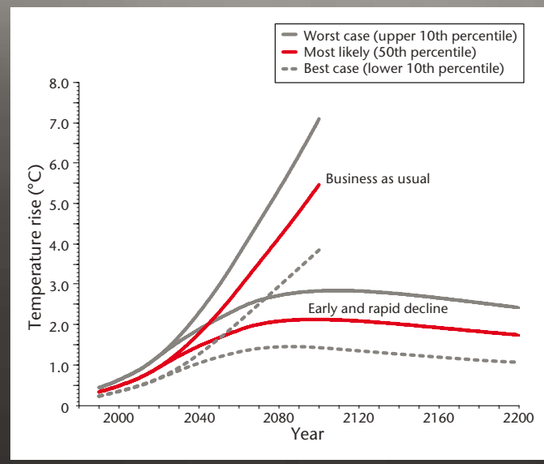


Figure: Shows the projected temperatures with the red line indicating the median projection (50% chance). The grey lines show the 10% best and worst case projections.

What is very clear is that some increase in temperature is inevitable in the next century and that the decisions and actions that the world takes now will have a profound impact on the climate later this century.

Even if emissions start to decrease in the next two years and reach a rapid and sustained rate of decline of 3% per year, temperatures are likely to rise to 1.7 °C above pre-industrial levels by 2050, and to around 2 °C by 2100. This is because carbon dioxide already in the atmosphere will be around for many years and the climate takes time to respond to these changes. Only the scenario with an early and rapid decline in emissions gets anywhere near to the 50% reduction in emissions by 2050, as recommended in the latest IPCC report to avoid large increases in temperature.

Two other scenarios are also significant. The consequences of a late decline in emissions are apparent by 2050. Delaying reduction of emissions to 2030 results in a further 0.5 °C of warming by 2050 compared with early, if slow, reduction from 2010. By the end of the century, the differences are even greater – more than 1 °C.

The consequences of an early but slow decline in emissions of 1% per year compared with a rapid decline appear to be small in 2050. However, they increase to 0.8 °C by the end of the century.

Overall, a delayed and slow decline in emissions would probably lead to nearly 2 °C more warming than an early and rapid decline in global emissions, a total temperature rise of 4 °C above pre-industrial levels.

The implications of these levels of temperature change are very serious, but the central projections are not the only things we should be worried about. When commentators look at these projections, they tend to concentrate on the most likely temperature rises.

However, if we are concerned about keeping the risks of dangerous climate change to a minimum we should also consider the worst-case outcome. This worst- case outcome will occur if the climate turns out to be particularly sensitive to increases in greenhouse gases and the Earth's biological systems cannot absorb very much carbon.

The risks of worst-case outcomes (i.e. a 10% chance of occurring) amplify much more quickly than the risks of most likely outcomes. For an early and rapid decline in emissions, the worst-case outcome is around 0.7 °C higher than the most likely temperature rise. With much slower action taken much later, the difference between the most likely and worst-case outcome is almost twice as big, at 1.2 °C.

This takes a worst-case temperature rise of under 3 °C to one just above 5 °C by the end of this century, bringing with it significant risk of dangerous impacts to our environment, society and economy.

A major reason for this amplification is the so-called 'carbon cycle effect'. Today, plants, soils and oceans absorb about half of the carbon dioxide emitted by man's activities, limiting rises in atmospheric carbon dioxide (CO_2) and slowing global warming. As temperatures increase this absorption is very likely to decrease. For example, plant matter in the soil breaks down more quickly at higher temperatures, releasing carbon more quickly and amplifying the warming trend. Methane and CO_2 released from the thawing of permafrost will also add to the warming. This carbon release is currently not included in the calculations and becomes more of a risk for larger temperature rises.

Hence the risks of dangerous climate change will not increase slowly as greenhouse gases increase. Rather, the risks will multiply if we do not reduce emissions fast enough.

Interaction between climate, chemistry and biology

Which gases are important for climate change?

Greenhouse gases and aerosols both contribute in different ways to global warming and pollution generally. We are working on new ways of comparing the effects of these species. For example, we will be able to compare the relative benefits of controlling black carbon and CO_2 emissions.

Mitigation of climate change is likely to require reductions in a range of greenhouse gas emissions, not just CO_2. The other greenhouse gases, such as methane, nitrous oxide, ozone and the halocarbons remain in the atmosphere for very different periods of time and have non-radiative as well as radiative effects on climate. They can affect plant biology, water availability and air quality, for example.

The relative importance of different gases is usually compared with CO_2 in terms of their global warming potentials. This compares their effect on radiative forcing, i.e. how much the atmosphere is warmed directly by them, over a specified period of time.

The Met Office Hadley Centre is using the results from complex climate models to develop improved methods for comparing the impact of these gases – which take account of all their effects. In particular, this will enable the effects of short-lived gases or atmospheric aerosols (that remain in the atmosphere for a few weeks) to be compared with the effects of long-lived gases (that remain for tens or hundreds of years).

For instance, it has been argued that reducing black carbon and tropospheric ozone in the atmosphere could be a 'quick win' to reduce climate change while developing the technology needed to reduce CO_2 emissions. This is only true if the black carbon and ozone emission cuts are not associated with an increase in CO_2 emissions. We have shown how a new measure, the global temperature change potential, could be useful in assessing how long the climate benefit of a particular reduction in black carbon emissions lasts as a function of the associated fuel penalty. This may help future decisions about air quality and control of climate change to be better integrated.

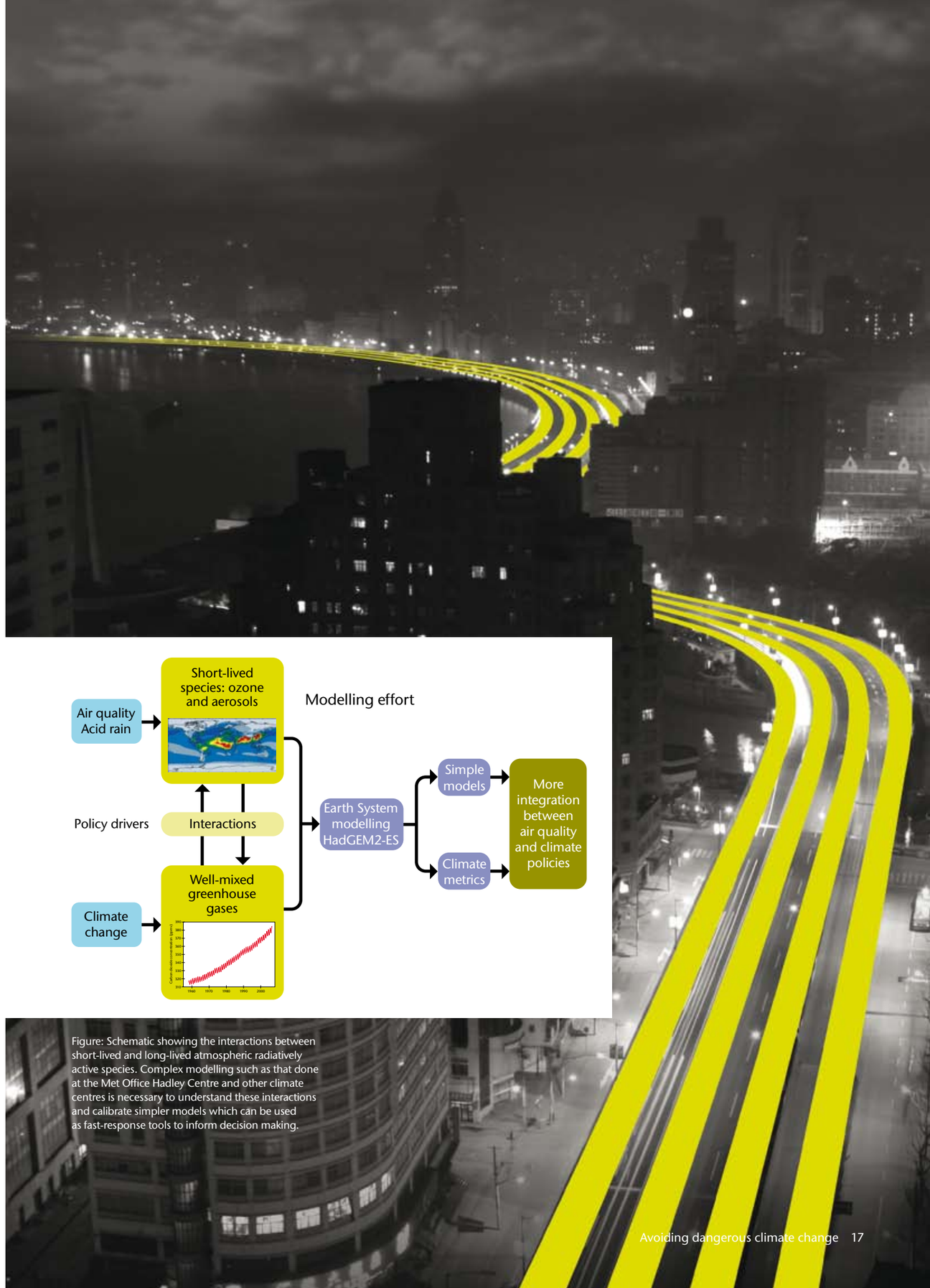


Figure: Schematic showing the interactions between short-lived and long-lived atmospheric radiatively active species. Complex modelling such as that done at the Met Office Hadley Centre and other climate centres is necessary to understand these interactions and calibrate simpler models which can be used as fast-response tools to inform decision making.

Impacts on air quality

The increase in surface ozone due to climate change is also expected to have a large impact on human health.

Actions to improve air quality and reduce climate change need to be linked. Ozone and aerosols, in particular, are important for both. In addition, complex interactions between climate, plants and chemistry change the amounts of the important gases and aerosols in the atmosphere. These issues need to be considered in decisions about climate change because worsening air quality is likely to increasingly affect human health.

Many greenhouse gases and aerosols important for climate change are also important for air quality and human health. For example, ozone contributes to global warming and is a powerful respiratory irritant at levels frequently found in urban areas. Aerosols or particulate matter contribute to both warming and cooling and exacerbate respiratory and cardiovascular diseases.

By the 2090s a significant fraction of the world's population will be exposed to ozone levels well above the World Health Organization (WHO) recommended safe-health level. Met Office Hadley Centre models project that increases will be large in all seasons, with more than a threefold increase in the percentage of population affected. In some regions — particularly industrialised developing countries such as India and China — increases will be considerably larger.

These issues mean that actions to improve air quality and reduce climate change need to be linked. A further driver for linking action to curb different types of pollution comes from new scientific evidence which shows much stronger interactions between the carbon cycle, tropospheric ozone and atmospheric aerosols than initially thought. These mean that all important climate change agents need to be considered simultaneously in determining their effects.

The Met Office Hadley Centre has shown that complex interactions between climate change agents through their impact on plant biology could have serious consequences for air quality and make climate change worse. Our results show that increased CO_2 reduces the removal of ozone by plants during the growing season, resulting in higher atmospheric ozone concentrations. Moreover, high levels of ozone damage the plants and reduce the rate of photosynthesis. This will, in turn, reduce the absorption of CO_2 by plants, leading to increased global warming; another example of a non-radiative interaction.

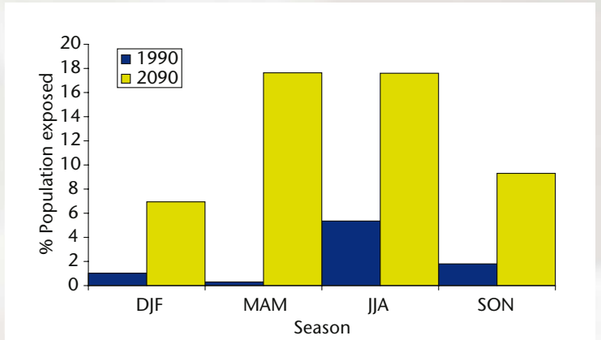


Figure: Percentage of world population exposed to ozone levels above the WHO recommended safe-health level of 60 parts per billion (ppb) for 1990 and 2090, modelled using the Met Office global climate model coupled to a chemistry model forced by a medium to high emissions scenario (IPCC SRES A2). Changes are influenced by ozone variations, with population held constant at 1990 levels. Note that these results are based on seasonal averages greater than 60 ppb whereas WHO guidelines are based on eight hour exposure above 60 ppb. A single eight-hour exposure may be considerably higher than the seasonal average. However, the A2 scenario is now thought to overestimate ozone values because it probably underestimates local pollution controls.

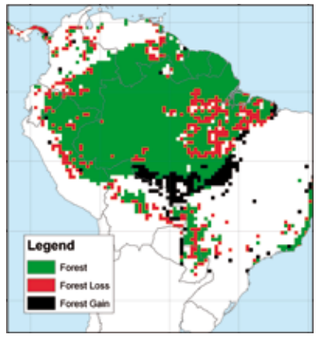
The impact of deforestation and land degradation

CO_2 emissions from deforestation are currently estimated to exceed those from transport.

New estimates of future deforestation are much larger than those used by IPCC and deforestation is already a major contributor to CO_2 emissions – larger than transport. Climate change puts further pressure on forests. Reductions in rainfall and associated increases in drought and fire risk add to the destruction of forest.

The Met Office Hadley Centre is assessing the potential impacts of ongoing deforestation on climate change and the extent to which reducing deforestation could contribute to stabilising greenhouse gas concentrations. Most current projections of future climate use the SRES emissions scenarios. However, these may significantly underestimate the amount of deforestation in critical regions, such as the Amazon.

The Figure compares deforestation estimate used in the SRES A2 scenario with two more recent estimates. With no controls on deforestation the area of forest lost could be five times greater than in the SRES scenario. Even with effective governance the loss could be double. Clearly, this could have a significant impact on carbon emissions. For example, global CO_2 emissions from forests are currently estimated to exceed those from transport. The next stage is to quantify the implications for stabilisation of the climate.



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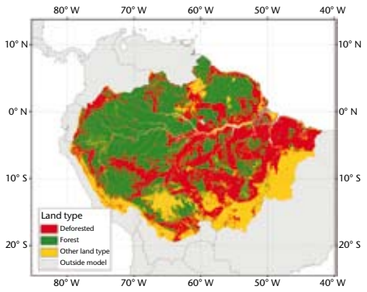

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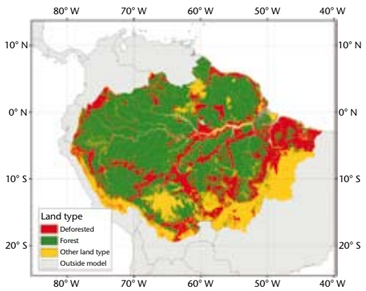

(c)

Figure: Projected deforestation in 2050 for:

(a) IPCC SRES A2 scenario, total area of Amazonia deforested 435,000 km^2. [4]

(b) scenario based on highway paving plans, current protected areas and legislation compliance, area deforested 2,067,000 km^2. [5]

(c) highway paving plans but greater implementation and enforcement of protected areas, area deforested 913,000 km^2. [5]

[4] (a) Strengers, B. et al. (2004) The land use projections and resulting emissions in the IPCC SRES scenarios as simulated by the IMAGE 2.2 model. GeoJournal, 61(4), 381-393.

[5] (b) and (c) Soares-Filho, B.S. et al. (2006) Modelling conservation in the Amazon basin. Nature, 440, 520-523.

In addition to man-made deforestation, climate change may cause the 'die-back' of the Amazonian forest. However, deliberate deforestation in Amazonia is likely to have a bigger impact in the short term. By avoiding deforestation in the first part of the 21st century, emissions would be reduced by up to 27 GtC by 2050. Furthermore, preservation of the forest would maintain a carbon sink due to CO_2 fertilisation of photosynthesis worth 4 GtC by 2050.

Climate change and deforestation are also likely to interact with each other. In previous drought events such as 2005, fires used for forest clearance became uncontrolled and larger areas were burnt through this 'fire leakage'. Climate change is likely to reduce rainfall in the region. Even if this does not directly damage plants very much through drought, it is likely to increase the risk of fire leakage which would magnify the impact of deforestation. The areas projected to experience an increase in fire danger due to climate change overlap considerably with the areas projected to undergo deforestation.

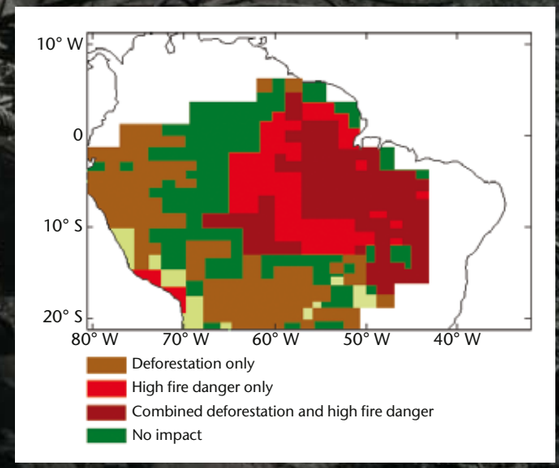

Figure: Projected overlap of deforestation and high fire risk for 2081-2090. Red areas show where all members of the Hadley Centre climate model ensemble agree on high fire risk.

Improvements in decision-making tools

International collaboration to compare information from different Earth System models will help improve our estimates of the maximum permissible emissions of carbon dioxide for a stable climate.

Climate change is strongly dependent on interactions between climate and many other aspects of the Earth System, such as plant and ocean biology. The new Met Office Hadley Centre Earth System model will include many of these interactions. It will be used to provide better advice on emissions reductions and the risks of dangerous climate change. It will also be used to look at the interactions which could amplify climate change and impact on other aspects of the environment such as air quality and ocean acidification.

The next generation of Earth System models will represent more complex feedbacks and improve climate projection accuracy. We are close to finalising our new Earth System model, HadGEM2-ES, which will include the land and ocean carbon cycles, dynamic vegetation, ocean biology, and atmospheric chemistry and aerosols. It will contribute to the forthcoming IPCC Fifth Assessment Report as part of an international collaboration to compare information from different Earth System models. This will help to improve our estimates of the maximum permissible emissions of carbon dioxide and other greenhouse gases to achieve a stable climate over the next few centuries.

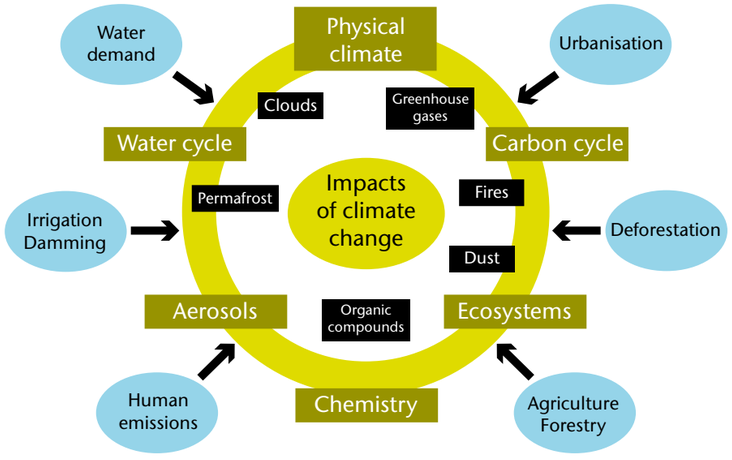

Figure: Earth System models include an increasing number of complex feedbacks between physical climate and biogeochemical cycles.

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